

**BALLISTIC PROTECTIVE ARMOUR AND BALLISTIC PROTECTIVE HELMET AND PROTECTIVE VEST**

5 The present invention relates to ballistic protective armour according to the preamble of claim 1, and a corresponding ballistic protective helmet and protective vest.

10 Ballistic protective armour of this type is a component of ballistic protective clothing or head coverings such as military helmets, bullet-proof vests and suchlike. For reasons to do with saving weight, such protective armour is generally made from technical fabrics such as high-molecular polyethylene, aramid or other highly durable yarns. Individual layers of fabric are laminated with the help of an adhesive matrix by applying an adhesive, a resin or a film between the individual textile layers, and the entire packet of 15 layers is then pressed to create a textile laminate.

20 The properties of the protective armour may be varied as a function of the material properties of the yarns used for the textile layers, the different types of weave and fabric weights, and the percentage of resin or adhesive in the connection matrix. Besides form stability, i.e. resistance to deformation, which is particularly important in protective helmets, resistance to an impacting projectile or fragments naturally plays a primordial role. In addition to exerting force in the layering direction, which will be referred to below as the Z direction, the impacting missile also exercises forces in the 25 directions within the plane of the layers, i.e. in the X and Y directions perpendicular to the Z direction. These forces are absorbed by the yarns or fibres of the textile layers, whilst the forces in the Z direction are absorbed by the bonding of the textile layers. This means that the adhesive strength of the matrix makes a decisive contribution to preventing the missile from 30 penetrating the armour.

35 It is possible to completely embed the layers of textile fabric in the matrix so that the adhesive force holding the layers to each other is very high. In general, the forces occurring in the X and Y directions upon impact of a missile cause the fabric fibres to stretch, thereby absorbing energy. As this happens, the protective armour may bulge in the direction of impact. If, however, a certain force or extension of the fibres is exceeded, the fibres are

1 abruptly sheared and the missile penetrates the corresponding layer. This  
shearing effect is exacerbated by completely embedding the fabric in the  
resin or adhesive matrix as this restricts the fibres in their capacity for  
longitudinal extension. This reduces resistance to perforation of the armour.  
5 Besides this effect, a high percentage of resin or adhesive increases the  
weight of the protective armour.

Attempts have therefore been made to construct ballistic protective armour  
with a reduced application of resin between the textile layers. This saves  
10 weight, and the energy absorption within the individual textile layers is  
increased as the fabric fibres not embedded in the matrix can stretch  
unhindered. On the other hand, the hold between the layers is reduced.  
Hence the following effect occurs upon impact of a projectile: as a result of  
15 the shearing effect, the outer textile layers are smoothly penetrated by the  
projectile, which is greatly deformed in the process. The following layers stop  
the projectile, whose kinetic energy is already greatly reduced by this point,  
thanks to the stretching of the fibres within the textile layers. As this  
happens, these stopping layers of the laminate bulge substantially towards  
20 the inside of the protective armour because the projectile-stopping layers  
detach more easily from the perforated layers due to the reduced application  
of resin, and delamination occurs between these layers. The pronounced  
bulging effect can, however, cause serious injury to the wearer of the ballistic  
protective clothing. The wearer of a ballistic protective helmet which is  
subjected to substantial inward deformation upon impact of a missile may,  
25 for example, suffer head injuries.

When designing conventional ballistic protective armour one must, therefore,  
prevent the above described effect of complete perforation on the one hand,  
whilst also preventing excessive deformation of the inner layers of the textile  
30 laminate on the other hand. This is done by appropriately matching the  
stretch properties of the textile fabric and the percentage of resin or  
adhesive, so that the load uptake in the various directions can be  
predetermined. This is only possible to a limited extent, however, because the  
conditions are difficult to reproduce during production of the protective  
35 armour, and because the delamination effect that occurs as the deforming  
stopping layers detach from the perforated layers is sudden and virtually  
uncontrollable. These circumstances render it extremely difficult to select, in

1 particular, the percentage of resin or adhesive to use in the connection  
matrix.

5 The task of the present invention is therefore to provide ballistic protective  
armour of the above-mentioned type which reliably prevents penetration by  
projectiles or impacting fragments but at the same time reduces the above-  
described deformation effect on the inside of the armour opposite the impact  
side to an acceptable degree, whilst keeping the weight of the protective  
armour as low as possible.

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This task is solved according to the invention by means of ballistic protective  
armour with the features of claim 1.

15 The ballistic protective armour according to the invention comprises a  
number of wire or thread binders which pass through the textile laminate in  
the layering direction, i.e. in the direction of the surface normals, which is  
perpendicular to the textile layers. These binders give the individual textile  
layers of the laminate additional hold relative to each other in that in  
addition to the prior art adhesive matrix, a further mechanical connection is  
20 created. By selecting an appropriate tensile strength, i.e. elasticity, of the  
binders it is possible to improve the perforation and deformation properties  
of the textile laminate and its resistance to an impacting projectile.

25 In particular, the above-described bulging effect in the inner stopping layers  
of the laminate which are deformed on projectile impact is greatly reduced as  
the binders can absorb large tensile forces in the direction of the missile, and  
can prevent an uncontrolled detaching of the layers from each other  
(delamination). Instead, the delamination effect is restricted to the immediate  
vicinity of the missile channel. In this region the tensile forces on the binders  
30 are so high that they break and the inner stopping layers can become  
detached. In the directions within the layers, i.e. in the directions  
perpendicular to the layering direction, the force finally decreases until it  
drops below the force required to snap the binders, so that the binders are  
merely stretched. The adhesive coatings on the layers may become detached  
35 from each other, but the layers themselves are held together in a stable  
manner by the stretched binders. This substantially reduces the degree of  
inward bulging in the protective armour, and hence the risk of injury. And

1 there is still sufficient absorption of the kinetic energy from the missile to  
ensure that the projectile is unable to completely penetrate the textile  
laminate. The percentage of resin or adhesive in the textile laminate can be  
substantially reduced without excessive deformation occurring, which results  
5 in weight savings and improved wearer comfort.

Advantageous embodiments of the ballistic protective armour according to  
the invention are disclosed in subclaims 2 to 18.

10 A ballistic protective helmet, whose helmet shell is formed by ballistic  
protective armour according to the invention, is claimed in claim 19.

Claim 20 is further directed at a ballistic protective vest comprising hard  
segments or hard inserts, each of which is formed by ballistic protective  
15 armour according to the invention.

Further embodiments of this protective vest are disclosed in claims 21 and  
22.

20 Preferred examples of embodiments of the invention will be described in more  
detail below with reference to the drawings, in which

25 Fig. 1 shows a side partial section through a ballistic protective  
helmet whose helmet shell is formed by ballistic protective  
armour according to the invention;

Fig. 2 shows a top plan view of a section of the surface of the helmet  
shell of Fig. 1;

30 Fig. 3 shows a partial section through a helmet shell according to a  
further embodiment of the invention;

Fig. 4 shows a top plan view of a section of the helmet shell of Fig. 3;

35 Fig. 5 shows the helmet shell of Fig. 3 in a deformed state after impact  
by a projectile, and

1        Fig. 6        shows a partial section through a helmet shell according to a  
third embodiment of the invention.

5        The helmet shell 10 shown in Figure 1 is a component of a ballistic protective  
helmet, for example a helmet for military use. The concave inside of the  
protective helmet closest to the helmet wearer's head (not illustrated) is  
shown at the bottom of the Figure, whilst a projectile may impact from the  
convex outer side. The term "projectile" as used hereafter includes all  
possible ballistic missiles, such as grenade or missile fragments or suchlike  
10      in addition to projectiles from firearms in the narrowest sense.

15      Other devices inside the protective helmet such as a basket-shaped lining  
attached to the inside of the helmet shell 10, which ensures a gap between  
the helmet wearer's head and the inside of the helmet shell 10 and improves  
wearer comfort, is not shown in this or any of the following figures.

20      Figure 1 shows the helmet shell 10 in intact condition. It is formed by  
ballistic protective armour 12 comprising a textile laminate 14 made from a  
number of textile layers which are laminated together. The layers run along  
the curve of the helmet surface, parallel to each other, between the inner and  
outer surfaces of helmet shell 10, i.e. the layering direction coincides with  
the surface normals, which is perpendicular to the surfaces of the textile  
layers. In Figure 1, the layering direction is designated by an arrow Z, which  
25      coincides with the normals of the outer helmet surface at a certain point of  
curvature, whilst the individual textile layers run in the X and Y directions  
inside helmet shell 10, perpendicular to layering direction Z. For the sake of  
completeness, the X direction (to the right in Figure 1) is also indicated by an  
arrow X.

30      For reasons of clarity, the textile layers are shown in cross-section in a  
region confined to the right of the Figure. The layers actually run through the  
entire helmet shell 10. The present embodiment specifically includes ten  
layers 16 to 34, layered on top of each other in the Z direction. In practice it  
is usual to use an even larger number of layers; the person skilled in the art  
35      will, however, be able to select an appropriate number of layers. Each of  
textile layers 16.....34 comprises a fabric made of aramid, polyethylene or  
carbon fibres, that is a synthetic material with high tensile strength in the

1 directions X and Y, in which the layer stretches. It is further possible to  
weave the textile layers out of yarns, or to produce them using other textile  
techniques.

5 Textile layers 16.....34 are laminated together in that they are pressed with a  
connection matrix disposed layer by layer between the individual textile  
layers. This connection matrix may be, for example, an adhesive, a resin or a  
pressable film. To produce the textile laminate 14, textile layers 16.....34 and  
10 adhesive or resin layers, or film layers, are thus alternately positioned one on  
top of the other and pressed under high pressure so that the textile laminate  
14 is created as a composite made of textile layers and the connection  
matrix. The individual layers of the connection matrix are not shown in more  
15 detail in Figure 1 or the following Figures. The stability of this packet of  
layers 14, i.e. its resistance to forces in the Z direction, which act to detach  
textile layers 16....34 from each other, and the weight of helmet shell 10 can  
be determined by the quantity of adhesive or resin applied, or the thickness  
of the pressable film between the textile layers. Basically, the greater the  
weight percentage of the connection matrix in relation to the total weight, the  
greater its strength, meaning that the strength can be increased by, for  
20 example, applying more resin. Doing so may, however, cause an effect  
whereby the material used for the connection matrix penetrates at least  
partially into the fabric of the textile layers 16...34 when the laminate is  
pressed, causing the fibres of the textile layers to become embedded in the  
matrix. This severely restricts the fibres' ability to stretch in the X and Y  
25 directions.

According to the invention, the ballistic protective armour 12 forming helmet  
shell 10 comprises a number of wire or thread binders 40, which pass  
30 through the textile laminate 14 in the layering direction Z from the inner  
surface of helmet shell 10 to the outer surface, i.e. through all the textile  
layers 16....34. These binders, which are spaced apart from each other in  
directions X, Y in which textile layers 16...34 run, ensure additional hold  
between the textile layers 16....34. Hence layers 16....34 are not held  
35 together solely by the adhesive force of the connection matrix, but also  
mechanically, by binders 40. This ensures greater stability of laminate 14 in  
the layering direction Z and, in the event of impact by a projectile, offers

1      advantageous properties in case of delamination of the inner textile layers, as  
will be described in more detail below.

5      Binders 40, of which only the left-hand binder 40 is provided with a reference  
numeral in Figure 1, can be made of any suitable material which exhibits the  
desired properties, i.e. appropriate tensile strength and elasticity in  
particular. Binders 40 may, for example, be made of a metal or a synthetic  
material, and possibly flexible reinforcing threads formed from a single fibre  
or a number of fibres which may further be spun or drilled to form a yarn.  
10     Highly durable materials such as aramid, polyethylene or carbon fibres are  
possibilities. Although not shown in Figure 1, it is conceivable that the ends  
of the individual binders 40 on the outside and inside of helmet shell 10 be  
provided with anchoring devices such as protuberances or suchlike to  
prevent binders 40 from simply being pulled out of the packet of layers in the  
15     event of delamination of the textile laminate 14.

20     To allow binders 40 to fulfil their function according to the invention it is not  
essential that binders 40 run precisely in the layering direction Z or -Z, i.e.  
in the direction of the surface normals of textile layers 16....34 at the point  
of penetration of binders 40, rather it is sufficient that the stretching  
direction of binders 40 includes a component which coincides with the  
layering direction Z, so that textile layers 16....34 are penetrated. Hence it is  
permissible to include a certain angle with the normals. If such deviations  
are desired for constructive reasons, the person skilled in the art will be able  
25     to determine a suitable size for the angle of deviation through tests not  
involving a great deal of work.

30     Figure 2 shows a top plan view of helmet shell 10 with the inserted binders  
40. In this figure all that is visible is a section of the surface of the  
uppermost textile layer 34, inside which lie the outermost ends of the wire or  
thread binders 40. The layering direction Z thus points out of the plane of  
the drawing in Figure 2. Binders 40 are arranged in a regular quadratic grid  
pattern, i.e. binders 40 are disposed in both the X and Y directions to  
35     coincide with the stretching direction of textile layer 34, positioned in rows at  
equal distances, a, from each other. Distances a may be freely selected in  
order to influence the stability of the textile laminate 14 and its delamination  
behaviour.

1 Figure 3 shows a lateral partial section through another helmet shell 50 which is also made from a textile laminate 14 comprising individual textile layers 16...34. The structure of the individual layers 16...34 made from a highly durable fabric, their layering in the Z direction and their connection  
5 by means of layer-upon-layer pressing with a connection matrix correspond to the helmet shell 10 of Figures 1 and 2, so that reference is made to the preceding sections of the description with regard to the structure of textile laminate 14.

10 According to the invention, helmet shell 50 comprises thread binders formed here by sections 52, running in the layering direction Z, of a reinforcing thread 54 which runs as an endless thread between the inner and outer surfaces of helmet shell 50 meandering through textile laminate 14 in direction X, i.e. in the direction in which textile layers 16...34 stretch.

15 Starting out on the left-hand side of Figure 3, a section 52 of reinforcing thread running in layering direction Z initially passes from the inside to the outside where it is joined by a connecting section 56, which rests on top of the outer surface of helmet shell 50, of reinforcing thread 54. This is in turn followed by a reinforcing thread section 52 which runs from the outside to  
20 the inside (opposite direction -Z), followed by a connecting section 56 which rests against the inside of the helmet shell. From here on, this sequence of sections of the reinforcing thread 54 between the inside and the outside repeats itself continuously in the stretching direction X of the textile layers 16....34. Hence the individual reinforcing thread sections 52 forming the  
25 binders are connected by connecting sections 56 to form an endless thread which creates a seam which can run through the entire textile laminate 14 and helmet shell 50. Reinforcing thread 54 can be pulled taut to give the individual textile layers 16...34 increased stability.

30 Reinforcing thread 54 may be a textile fibre made from a highly durable synthetic material such as aramid, polyethylene or carbon fibre, and several fibres of reinforcing thread 54 can be spun or drilled together to form a yarn. Basically, the same materials can be used for binders 40 in the first embodiment and for reinforcing thread 54, respectively sections 52 of it  
35 acting as binders. Given that, in the case of the endless reinforcing thread 54, the thread path undergoes deflections at the inner and outer surfaces of

1 helmet shell 50, the thread material needs to exhibit a certain pliancy and  
flexibility.

5 Figure 4 shows a top plan view of a section of the outermost textile layer 34  
from the same perspective as in Figure 2. Resting on the surface of the textile  
layer 16 one can recognise connecting sections 56 of reinforcing thread 54,  
whilst at the ends of connecting sections 56, reinforcing thread sections 52  
run in the layering direction and opposite thereto (directions Z and -Z) into  
textile laminate 14 and out again. In Figure 4, the seams of endless threads  
10 54 run from left to right, and connecting sections 56 are the same length on  
the inside and outside of helmet shell 50. Endless threads 54 are spaced  
apart in the direction perpendicular to the direction in which the seams run,  
and connecting sections 56 of adjacent connecting threads 54 are each  
15 staggered by the length of one connecting section 56 in relation to each other  
in the direction in which the seams run.

20 It is understood that a different seam path may also be selected, for example  
by forming loops within the path of reinforcing thread 54, as will be  
explained below. Furthermore, as in the previously described embodiment, it  
is not necessary for reinforcing thread sections 52 to run precisely in the  
direction of the surface normals; deviations from this direction can be  
tolerated. For example, consecutive reinforcing thread sections 52 may be  
inclined in relation to each other such that a W or zigzag type path results in  
the perpendicular sectional plane through laminate 14.

25 Figure 5 shows the functioning principle of the ballistic protective armour  
according to the invention with reference to the second embodiment depicted  
in Figures 3 and 4. In this case it is assumed that helmet shell 50 is shot at  
with a projectile 60 which impacts absolutely perpendicular to helmet shell  
30 50, i.e. in a missile direction -Z. Upon impact projectile 60 penetrates a  
number of outer textile layers, whereupon the fibres inside the textile layers  
are sheared smoothly, producing an approximately cylindrical missile  
channel 62. The projectile 60 is greatly deformed as this happens and its  
kinetic energy is partially absorbed until the energy is no longer sufficient to  
35 penetrate further layers. This causes a deformation in the form of an inward  
bulge in the remaining textile layers on the inside of helmet shell 50 because  
the remaining energy from projectile 60 stretches the fibres of the textile

1 layers which are not penetrated. Projectile 60 then remains inside a cavern  
2 64 between the outer and inner textile layers. This cavern 64 is formed  
3 because the outer penetrated textile layers essentially retain their outwardly  
4 curved shape whilst the deformation of the inner layers causes a detaching  
5 or delaminating effect in that the outer and inner layer packets become  
detached from each other in the vicinity of missile channel 62.

10 In Figure 5, the three outermost textile layers 30,32,34 are smoothly  
11 penetrated and missile channel 62 forms inside them whilst the four  
12 innermost layers 16 to 22 bulge inwards. The fabric of these textile layers 16  
13 to 22 remains intact, the fibres of the fabric are merely stretched so that the  
bulge is formed towards the inside of helmet shell 50. Between the  
14 penetrated layers 30,32,34 and the deformed layers 16 to 22, which are also  
15 referred to as stopping layers, there are three textile layers 24,26,28 which  
are destroyed in the immediate vicinity of missile channel 62, absorbing  
energy as a result.

20 When stopping layers 16 to 22 detach, the inner stability of textile laminate  
21 14 provided by the connection matrix is destroyed and there is a risk that  
uncontrolled detaching of the layers may cause substantial bulging and  
hence injury to the helmet wearer. According to the invention, this  
22 disadvantageous effect is prevented by reinforcing thread 54. The sections 52  
23 of reinforcing thread 54 running in the layering direction Z are able to absorb  
the tensile forces occurring in the Z direction upon impact, which stretches  
24 reinforcing thread 54 along sections 52, so that additional energy is  
absorbed. If the forces exceed a certain value, reinforcing thread section 52  
snaps. As the force decreases in the lateral direction, i.e. in the X and Y  
25 directions in relation to the direction of the missile, this snapping effect only  
occurs in the vicinity of the missile channel 62, as shown in Figure 5.  
26 Further away from missile channel 62 the tensile forces decrease and can be  
absorbed by the sections 52 of reinforcing thread without snapping thread  
27 54. In this fashion the adhesive layer of the connection matrix between the  
penetrated layers 30,32,34 and the stopping layers 16 to 22 can be prevented  
from giving way uncontrollably. The reinforcing thread sections 52 at the  
28 outer regions of cavern 64 reliably limit the delamination effect. The  
absorption of the tensile forces by the reinforcing thread sections 52 is  
facilitated by the outer ends of sections 52 being anchored in the outer

1 textile layers 30,32,34 which retain their curved shape and hence exhibit  
high stability against the tensile forces exerted by reinforcing thread sections  
52. This anchoring effect in the outer layers 30,32,34 gives greater stability  
to sections 52, and hence to the inwardly deformed region of the inner  
5 stopping layers 16 to 22.

10 It is understood that the effect of the binders according to the invention as  
shown in Figure 5 is illustrated through reinforcing thread sections 52  
merely by way of example, and is similarly achieved by all kinds of binders as  
defined in the present invention, in particular by binders 40 according to the  
first embodiment.

15 The energy absorption within textile laminate 14 can be advantageously  
increased by configuring the outer layers 30,32,34 in which missile channel  
62 is formed to be very hard in comparison to the subsequent middle layers  
24,26,28 which are destroyed in the region of cavern 64, thereby absorbing  
energy. The great hardness of outer layers 30,32,34 greatly deforms projectile  
60, which has to form a larger penetration channel to allow it to penetrate  
20 more deeply into textile laminate 14. In order to guarantee good  
deformability, the hardness of stopping layers 16 to 22 on the inside of  
helmet shell 50 should advantageously be selected so that it lies somewhere  
between the hardness of outer layers 30,32,34 and that of the soft middle  
layers 24,26,28. The hardnesses of the various layers 16...34 can be  
25 influenced by the choice of fabric, and in particular, by the percentage of  
resin or adhesive in the connection matrix in the textile layers 16....34.

30 Finally, Figure 6 shows a helmet shell 70 similar to the helmet shell 50 of  
Figures 3 to 5, in which the seams of reinforcing threads 54 follow a different  
path. On the opposite surfaces of textile laminate 14, reinforcing threads 54  
run as endless threads, of which each endless thread comprises a number of  
loops 72 projecting into textile laminate 14, said loops being interlooped with  
the loops 72 of an endless thread running across the opposite surface of  
textile laminate 14. That means loops 72 of the reinforcing thread 54 that  
rests against the outside of helmet shell 70 point into textile laminate 14  
35 counter to layering direction Z through a channel not shown in more detail  
and in the region of the middle textile layers engage in the loops 72 of  
another endless thread 54 running in a similar manner along the inside of

1 the helmet. Each pair of interlooped loops 72 therefore forms a binder  
according to the invention. The loops 72 can be tensioned more or less tautly  
to permit adjustment of the elastic properties of the tensioning.

5 Ballistic protective armour 12 of the type described here is suitable not only  
for helmet shells 10,50 of ballistic protective helmets, but also for other  
kinds of ballistic protective clothing, in particular for protective vests  
designed to protect their wearer from projectiles or fragments. As such  
protective vests need to exhibit a certain flexibility for reasons to do with  
10 wearer comfort, the prior art vests usually include hard segments or hard  
inserts at points which are particularly at risk. These hard segments or  
inserts can also be formed from the ballistic protective armour according to  
the invention. To guarantee unbroken protection without restricting the vest  
wearer's freedom of movement it is advantageous to select an arrangement  
15 whereby the hard segments or hard inserts overlap each other, but can be  
displaced with respect to each other, or engage with each other.

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